Towards Augmented Reality Interfaces for Human-Robot Interaction in Manufacturing Environments

Shelly Bagchi
National Institute of Standards and Technology
Gaithersburg, MD
shelly.bagchi@nist.gov

Jeremy A. Marvel
National Institute of Standards and Technology
Gaithersburg, MD
jeremy.marvel@nist.gov

ABSTRACT

As part of the U.S. Department of Commerce, the National Institute of Standards and Technology (NIST) is examining new approaches to increase the competitiveness of smaller U.S.-based manufacturers. Collaborative robotics is one way to increase automation, leveraging the specialized skills of human workers along with the increased repeatability and throughput of robots. However, in order for humans to efficiently work alongside robots, new types of interfaces are needed to streamline interactions. Augmented reality, especially wearable devices, are a new approach that can enable task training, hands-free interactions, and increased safety through situational awareness. This paper will explore some preliminary approaches to integrating augmented reality for a collaborative manufacturing environment.

CCS CONCEPTS

• **Human-centered computing** → *HCI design and evaluation methods*; *Interactive systems and tools*; Ubiquitous and mobile devices; • **Computer systems organization** → **Embedded systems**; Robotics;

KEYWORDS

augmented reality, human-robot interaction, manufacturing, interfaces, metrics, industrial robots

ACM Reference Format:
Shelly Bagchi and Jeremy A. Marvel. 2018. Towards Augmented Reality Interfaces for Human-Robot Interaction in Manufacturing Environments. In *Proceedings of ACM Human-Robot Interaction Conference, Virtual, Augmented, and Mixed Reality Workshop (VAM-HRI).* ACM, New York, NY, USA, Article 8, 3 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

Automation, particularly the use of robotics, is becoming more prevalent among the larger U.S. manufacturers [1, 10], and this trend has been predicted to continue growing exponentially in the near future [12]. Recent trends show robots are increasingly being used in small- and medium-sized enterprises (SMEs) as well, principally due to decreasing costs and advances in safety [8]. In particular, collaborative robots offer SMEs the advantage of decreased training overhead and increased safety without requiring changes in the work environment to accommodate cages, thus leading to greater flexibility and multi-purpose use [7].

Current off-the-shelf collaborative robots, however, are generally only collaborative in the sense that they are expected to be safety-rated to operate near humans, incorporating force-limited motions or collision avoidance. To enable truly collaborative tasks that can leverage the abilities of existing human workers, not only do robots need to be aware of their environment and human partner(s), but human-facing interfaces need to evolve as well to enable real-time, two-way communication. Traditional teach pendant interfaces do not typically allow for easy or convenient use while also performing a task. Likewise, teach pendants make it difficult to obtain feedback or task status from the robot in an easy and efficient manner. New types of interfaces need to be developed to simplify interactions and incorporate system diagnostics, prognostics, and situation awareness (SA) before truly collaborative robotics can become a reality.

Augmented Reality (AR) technology has advanced rapidly in recent years. Now that such devices are widely available commercially, their acceptance is becoming increasingly common as their reliability improves. This increased acceptance and reliability enables integrators to leverage their use as human-robot interaction (HRI) interfaces for industrial applications. In particular, wearable AR devices have been shown to increase situational awareness (SA) and lead to better task performance [3], as well as grounding in the robot state [4].

Most AR devices can be split into two categories: "see-through" or monitor-based displays [9]. As the name implies, see-through displays project information onto a transparent medium that permits users to retrieve information without having to divert attention from the principal area of focus. Monitor-based displays, in contrast, require the user to focus attention on a separate display or interface through which the world is observed. This paper will explore multiple types of AR interfaces and their differing uses as industrial robot interfaces. As prototype interfaces are developed, future work will allow the collection of user data and enable further conclusions about the utility of AR devices for HRI.

2 WEARABLE DEVICES

In the category of see-through, wearable AR technology, there are generally two types of devices available: headsets and smart glasses. Smart glasses, such as Google Glass or Vuzix Blade, generally have one small screen projected into the user's direct or peripheral view. Notably, the smaller form factor of these devices makes it difficult to incorporate advanced sensing beyond a single camera and microphone. Natural language control is possible, but may not be as

VAM-HRI, March 2018, Chicago, IL USA

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM…$15.00
https://doi.org/10.1145/nnnnnnn.nnnnnnn

useful in a loud manufacturing environment. This limits the user's interaction with the real world through virtual objects ("mixed reality") as well as the user's communication with the robot, and thus limits the application of these devices in HRI.

For the purpose of industrial collaborative robotics, AR headsets such as Microsoft's HoloLens or the Meta 2 from Meta Company are more frequently being considered. There are also manufacturing-specific devices being developed, such as the DAQRI Smart Helmet, that are directly integrated into personal protective equipment (PPE) so as to ensure safety even while using immersive interfaces. Untethered headsets with wireless communication capabilities are ideal for performing manufacturing tasks while communicating with a robot partner. Additionally, these devices contain multiple cameras and inertial measurement units (IMUs) to perform head tracking and hand gesture recognition. The ability to project larger, three-dimensional holograms, as well as perform object recognition and other perception techniques, makes these AR devices promising for HRI applications.

2.1 Task Augmentation

Smaller manufacturers are often retasking their industrial robots for new products or applications [5, 11]. When retasking, human workers must be trained and industrial robots must be programmed before new production can begin. AR headsets can be useful on both sides of this equation by performing task-specific environment augmentations.

While wearing an AR headset, task training for the operator could be performed in an abbreviated training session or potentially even on-the-job. For example, relevant parts for an assembly can be identified by the headset and highlighted in the kit tray using a holographic overlay. Instructions can appear to the user textually, graphically, or verbally, depending on the situation or the user's preferences. The robot's part of the collaborative task can be identified by the headset as well, allowing the human to train it using the AR control interface, or other options such as kinesthetic learning or teaching by demonstration. In this way, both task partners can benefit from the AR interface.

Task augmentation can also be performed as a method of error detection. In the case that the wrong part is chosen for an assembly, for instance, the headset's perception system could detect a mismatch and alert the operator. This should save time down the line in the quality assurance process.

2.2 Robot Feedback

Similar to error detection, robot fault detection can be integrated into an AR interface. The robot constantly reports its status to the headset, which can monitor several relevant parameters such as joint torque limits or Cartesian speed. Should a given parameter begin to approach its limit, the headset can alert the operator to the issue and display potential causes or methods of handling the issue.

The robot can also use communication with the headset to query its human teammate. There may be issues where the robot's perception system is occluded or unsure which object is the goal, or an object may be out of the robot's reach. The robot can transmit these types of questions to the user – in text, visually, or verbally through natural language processing – to get assistance and make use of human knowledge or flexibility.

2.3 Situation Awareness

In addition to robot fault reporting as discussed above, there are multiple ways AR headsets and interfaces can improve operator situation awareness and grounding. One such option is for the robot to inform the operator of its next action, either through a virtual model (hologram) or by highlighting objects in the environment. This would allow the human teammate to adjust their actions accordingly, helping accomplish preconditions for the robot's next task, and potentially improving safety as the human knows the robot's intent. The operator can also intervene if the robot intends to perform the wrong task or has the potential of colliding with other objects. In this way, the collaborative task can take advantage of the robot's efficiency while still incorporating human oversight. Additionally, the human knows more about the robot's current state, and potentially feels more comfortable working directly with the robot.

3 PORTABLE DEVICES

On the opposite side of the spectrum from see-through or wearable devices are simpler devices with display screens and rear cameras (e.g., tablets and smart phones). These consumer devices are widely available for a relatively low price point, and can execute AR software comparable to headsets without the low screen real estate of smart glasses. External camera feeds can also be used with any computer, but are not significantly different from existing interfaces, so they will not be discussed here. Tablets are particularly interesting due to the potential of touchscreen interfaces. The recent prevalence of touchscreen devices means that interfaces on similar devices will require less training for novice users. The portable nature of these devices also gives them further utility for use in technical support and diagnostics applications.

3.1 Diagnostics & Prognostics

An example scenario we have envisioned for walk-up diagnostics is as follows: A technician is making the rounds of the industrial robots on a factory floor. At each robot, they use their tablet camera to scan an AR target (an image or other symbol, defined ahead of time). The scan connects them to the particular robot they are examining, via the factory's local wireless network, and launches the AR application. The technician can now point the camera at the robot, which is overlaid with a virtual model displaying the current robot status – for example, the torque at every joint. Problem areas reported by the robot will be highlighted in the AR view. Additionally, the technician can easily control the robot via the touchscreen interface to test operations or access areas in need of service.

Figure 1 shows a prototype tablet interface that incorporates several of the features mentioned above. A virtual model of the robot appears after scanning the image target shown in the photo (here a printed photo of the robot in question). Joint-specific controls show on the right side of the screen, along with options for communicating with the non-virtual robot. The robot's current configuration is updated live through both the virtual avatar and the joint sliders. Through this type of interface, a technician can

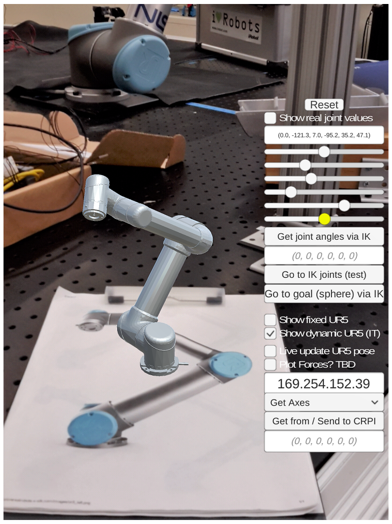

Figure 1: Prototype tablet interface using Augmented Reality technology.

observe and monitor the robot, as well as control it and receive relevant status information of the robot's current task.

4 EVALUATION & FUTURE WORK

Before new technology will be accepted by manufacturers, it must be thoroughly tested for performance, reliability, and safety. SMEs, in particular, have lower risk-tolerance, which may prevent them from investing in technologies that have not been exhaustively evaluated, or vetted through broad industry use [13]. Therefore, we intend to conduct a comprehensive study into the benefits of AR interfaces as compared to current methods.

Currently, several versions of AR interfaces for HRI are in development. These include headset, tablet, and touchscreen desktop applications. Once development is completed, user studies are planned to compare these interfaces to more traditional interfaces such as a teach pendant. This will allow us to collect user data in the form of both objective and subjective measures. For the former, these might include performance metrics such as task completion time or measures of success. For the latter, participants will be asked to evaluate each interface according to their preferences, answering post-task survey questions on a Likert scale. In addition, measures of mental workload will be collected from the Task-Load Index (TLX) developed by the National Aeronautics and Space Administration (NASA) [6], and task situation awareness will be measured from the situation awareness rating technique (SART) or the situation awareness global assessment technique (SAGAT) tests [2].

Collecting a wide variety of metrics and surveying a large pool of participants will allow us to draw conclusions about the strengths and weaknesses of each type of interface. Ultimately, our goal is also to evaluate which metrics are most important for HRI interfaces. In this way, we can help guide the creation of commercial HRI interfaces that have proven performance, are thoroughly safety tested, and held to accepted standards – thus more likely to be adopted in industrial settings.

5 CONCLUSIONS

As manufacturers move towards greater automation, new types of technology are needed to create a truly collaborative working environment. Augmented Reality can be a very useful tool for making human workers more effective, particularly for human-robot collaboration. As robot interfaces, AR devices can provide not only effective robot control, but also task training, feedback, and better SA. The process of robot diagnostics, root cause analysis, health monitoring, and prognostics can also be improved through the use of AR. In the future, we expect to quantitatively evaluate the potential performance benefits of AR used for HRI.

DISCLAIMER

Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

REFERENCES

[1] B. Doyle. 2015. North American Robotics Market Sets New Records in 2015. (2015). "http://www.robotics.org/content-detail.cfm/Industrial-Robotics-News/North-American-Robotics-Market-Sets-New-Records-in-2015/content_id/5951"

[2] Mica R Endsley and Debra G. Jones. 2016. *Designing for situation awareness: An approach to user-centered design.* CRC press.

[3] Scott A. Green, Mark Billinghurst, XiaoQi Chen, and J. Geoffrey Chase. 2008. Human-Robot Collaboration: A Literature Review and Augmented Reality Approach in Design. *International Journal of Advanced Robotic Systems* 5, 1 (2008), 1. https://doi.org/10.5772/5664 arXiv:https://doi.org/10.5772/5664

[4] S. A. Green, J. G. Chase, X. Chen, and M. Billinghurst. 2008. Evaluating the Augmented Reality Human-Robot Collaboration System. In *2008 15th International Conference on Mechatronics and Machine Vision in Practice.* 521–526. https://doi.org/10.1109/MMVIP.2008.4749586

[5] V. C. Gungor and G. P. Hancke. 2009. Industrial Wireless Sensor Networks: Challenges, Design Principles, and Technical Approaches. *IEEE Transactions on Industrial Electronics* 56, 10 (Oct 2009), 4258–4265. https://doi.org/10.1109/TIE.2009.2015754

[6] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Adv. Psychol.* 52 (1988), 139–183.

[7] J. Marvel. 2014. Collaborative Robotics: A Gateway into Factory Automation. (2014). http://news.thomasnet.com/imt/2014/09/03/collaborative-robots-a-gateway-into-factory-automation

[8] Jeremy Marvel, Elena Messina, Brian Antonishek, Lisa Fronczek, and Karl Van Wyk. 2015. *NISTIR 8093: Tools for collaborative robots within SME workcells.* Technical Report. National Institute of Standards and Technology.

[9] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. 1995. Augmented reality: a class of displays on the reality-virtuality continuum. (1995), 2351 - 2351 - 11 pages. https://doi.org/10.1117/12.197321

[10] M. Orcutt. 2014. Robots Rising. (2014). "https://www.technologyreview.com/s/529971/robots-rising/"

[11] Craig Schlenoff, Tsai Hong, Connie Liu, Roger Eastman, and Sebti Foufou. 2013. A literature review of sensor ontologies for manufacturing applications. In *Robotic and Sensors Environments (ROSE), 2013 IEEE International Symposium on.* IEEE, 96–101.

[12] L. Wood. 2014. Research and Markets: Global Articulated Robots Market Growth of 16.272016-2019. (2014). "http://www.businesswire.com/news/home/20160108005449/en/Research-Markets-Global-Articulated-Robots-Market-Growth"

[13] M. Zimmerman and J. Marvel. 2017. Smart Manufacturing and The Promotion of Artificially-Intelligent Human-Robot Collaborations in Small- and Medium-sized Enterprises. In *Association for the Advancement of Artificial Intelligence 2017 Fall Symposium Series.*